Wireless Communication for Traffic Signal Systems

For: Metropolitan Transportation Commision
Technology Transfer Program

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Presentation Outline

I. Transmission Media Considerations

II. Overview of Wireless System Technologies

III. Wireless System Considerations for Signal System Networks

Transmission Media Considerations

Wireline Systems

Wireless Systems

Wireline versus Wireless

Hybrid Systems

Wireline Systems

- Twisted pair
- Fiber
- Coaxial
- Leased Lines
  - Telephone
  - ISDN
  - DSL
  - T-1, T-3

Wireless Systems and Technologies

- Licensed frequencies (proprietary)
- Spread spectrum (proprietary)
- 802.11 (Wi-Fi)
- 802.16 (WIMAX)
- Cellular
  - AMPS
  - D-AMPS
  - CDPD
  - GSM/GPRS
  - CDMA
  - UMTS
- DSRC

Wireline vs. Wireless

- Wireline considerations

Advantages	Disadvantages
▪ Many high bandwidth applications ▪ High reliability (up-time) ▪ Long transmission distance	▪ High installation $$ ▪ Susceptible to damage from other construction ▪ Network typically limited to road alignment

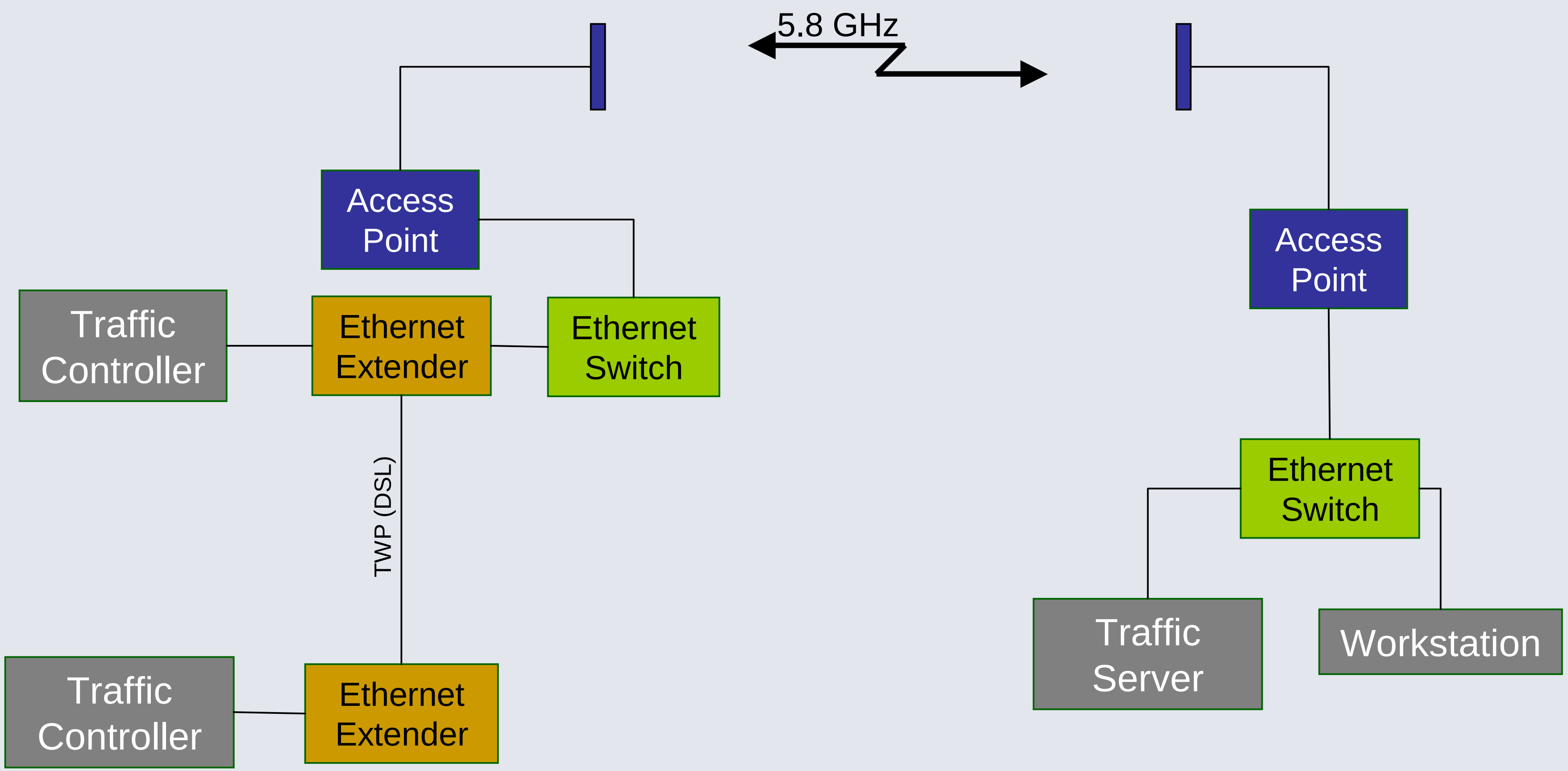
- Wireless considerations

Advantages	Disadvantages
▪ High reliability with line-of-sight (as the crow flies) ▪ Low installation $$ ▪ Bridging a gap between wireline systems ▪ Ability to broadcast radially with proper equipment ▪ Good for point-to-point trunking ▪ Rapid deployment, limited disruption to traffic	▪ Currently limited to low and medium bandwidth applications ▪ Susceptible to signal obstructions, e.g., new buildings ▪ Service driven by line-of-sight ▪ Limited channel capability in urban areas ▪ Limited vendors

Hybrid Systems

- Combination of wireline and wireless technologies in a single system
  - Private wireline to leased wireless service, e.g., twisted pair to 802.11
  - Private wireless to leased wireline service, spread spectrum to T-1

Hybrid System



The Radio Spectrum

Point-to-Multipoint Systems

Point-to-Point Systems

Cellular Systems

Radio Spectrum

- 30KHz to 3 GHz:
  - AM Radio: 540 – 1800 KHz
  - FM Radio: 88MHz - 108 MHz
  - Cellular (AMPS): 824 – 849, 869 – 894 MHz
  - Cellular (GSM): 890 – 915, 935 – 960 MHz
  - PCS: 1800 – 2200 MHz
- Microwaves: 3 GHz – 300 GHz
- Infrared Spectrum: 300 GHz – 300 THz
- Industrial, Scientific and Medical (ISM) Bands: 900-928 MHz, 2.4-2.5 GHz, 5.725-5.875 GHz, 24-24.25 GHz

Spectrum for Public Safety

- Broadcast TV spectrum to be freed up for public safety uses (police and fire) and public transit
- Two spectrums:
  - Channels 63/64 (765-775 MHz)
  - Channels 68/69 (795-805 MHz)

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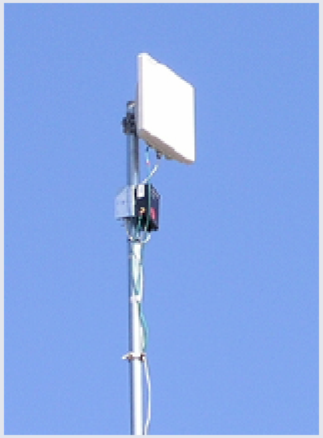
Point-to-Multipoint Systems

Wireless Fidelity (Wi-Fi)

Worldwide Interoperability for Microwave Access (WIMAX)

Dedicated Short Range Communications (DSRC)

Wireless Fidelity (Wi-Fi)



- A local area wireless standard (IEEE 802.11) intended for indoor and short range applications
- Utilizes Ethernet for data transport (packet-switched)
- Network access is based on contention, i.e., first-come, first-served basis
- Half-duplex (send or receive, not both at the same time)
- 802.11a: 54 MBps theoretical maximum bandwidth on a 20 MHz channel
- Actual throughput is typically less than half of the theoretical maximum
- Point-to-point system requires line-of-sight

Wireless Fidelity (Wi-Fi)

IEEE 802.11 Standards			
	802.11a	**802.11b**	**802.11g**
Max. Data Rate	54 MBps	11 MBps	54 MBps
Frequency	5Ghz	2.4Ghz	2.4Ghz
Modulation	OFDM	DSSS	DSSS
Channels	12	11	11
Bandwidth Available	300 MHz	83.5 MHz	83.5 MHz (22MHz per channel)
Power	40-800mW	100mW	100mW

OFDM=Orthogonal Frequency Division Multiplexing; DSSS=Direct Sequence Spread Spectrum.

Wi-Fi Elements

Wi-Fi Elements

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Wi-Fi Applications

- As a trunkline for a group of traffic signals
- As a dedicated link for one or more CCTV cameras
- Requires all connected devices to be encoded and assigned an IP address

WIMAX

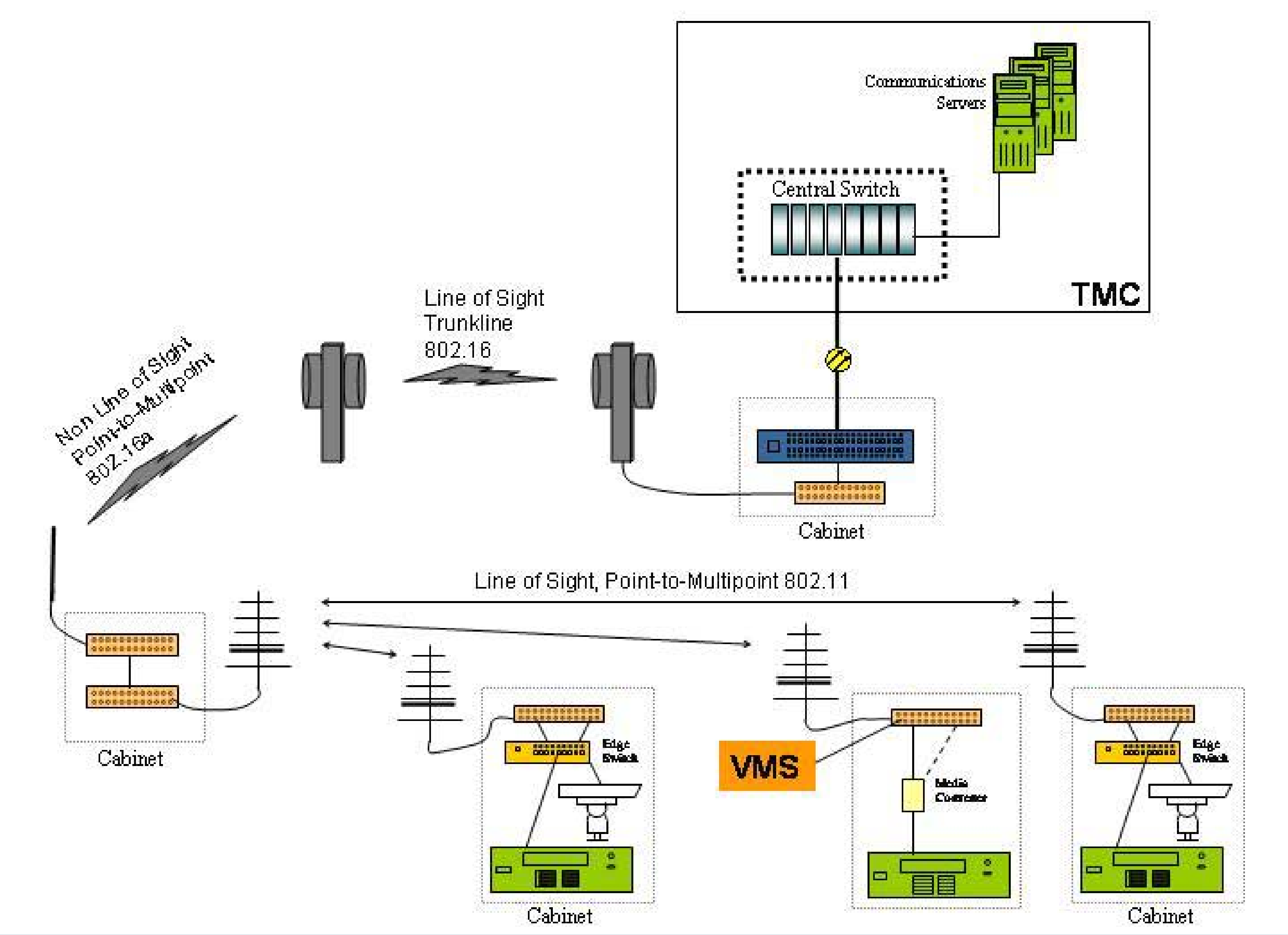
- Worldwide Interoperability for Microwave Access (WIMAX)
- Fixed wireless technology (IEEE 802.16)
- Will operate in the 3 to 66 GHz spectrums
- Range of up to 50Km
- Product rollout began Fall of 2003
- Network access is based on granting a request to connect and establishing a dedicated connection
- Up to a 100 MBps theoretical maximum on a 20 MHz channel
- Similarly to 802.11, actual throughput is typically less than half of the theoretical maximum

WIMAX

Description	802.16	802.16a/802.16revD	802.16e
Completion Date	Dec. 2001	802.16a Jan. 2003, 802.16revD, June 2004	2nd Quarter 2006
Spectrum	10 to 66 GHz	< 11 GHz	< 6 GHz
Channel Conditions	Line of Sight only	Non-Line of Sight	Non-Line of Sight
Bit Rate	32 to 134 MBps (28 MHz channels)	75 MBps max (20 MHz channels)	15 MBps max. (5 MHz channels)
Modulation	QPSK, 16QAM, 64QAM	OFDM, 256 subcarriers, QPSK, 16QAM, 64QAM	Same as 802.16a
Mobility	Fixed	Fixed	Pedestrian mobility, regional roaming
Channel Bandwidths	20, 25, and 28 MHz	Selectable between 1.25 and 20 MHz	Same as 802.16a with uplink subchannels
Typical Cell Radius	1 to 3 miles	3 to 5 miles (30 miles max based on tower height, antenna gain, and transmit power)	1 to 3 miles

Source: WiMAX Forum
QPSK=Quadrature Phase Shift Keying; QAM=Quadrature Amplitude Modulation; OFDM=Orthogonal Frequency Division Multiplexing

WIMAX and Wi-Fi



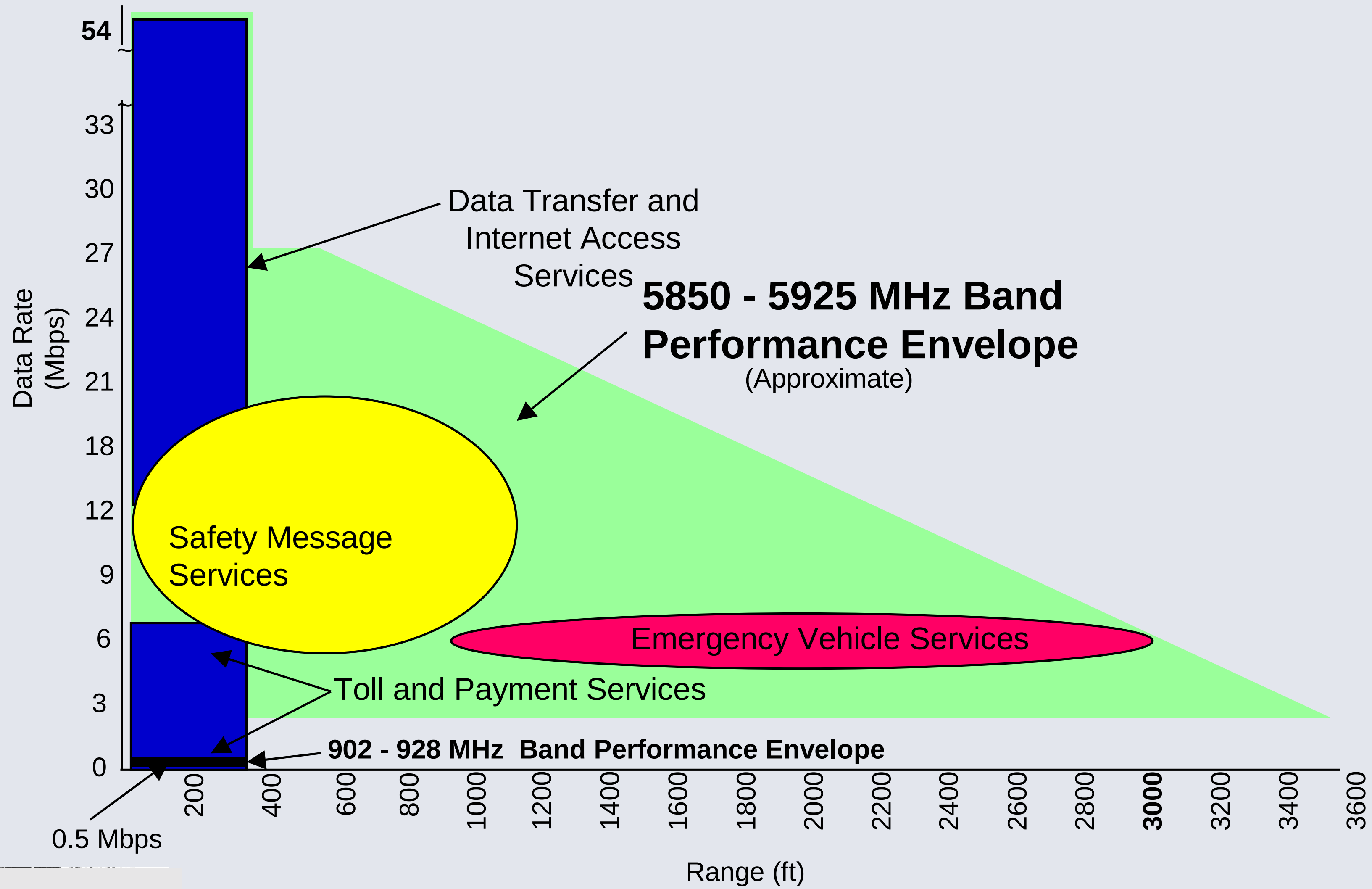
DSRC

- Dedicated Short Range Communications
- Communication in the 5.9 GHz spectrum
- Short to medium range communications service
- Supports both Public Safety and Private operations
- Roadside-to-vehicle and vehicle-to-vehicle communication environments
- Complements other communications links by providing very high data transfer rates with minimal latencies
- Primary communications for Vehicle Infrastructure Integration (VII)
- Future applications include toll tag systems and transit signal priority (TSP)

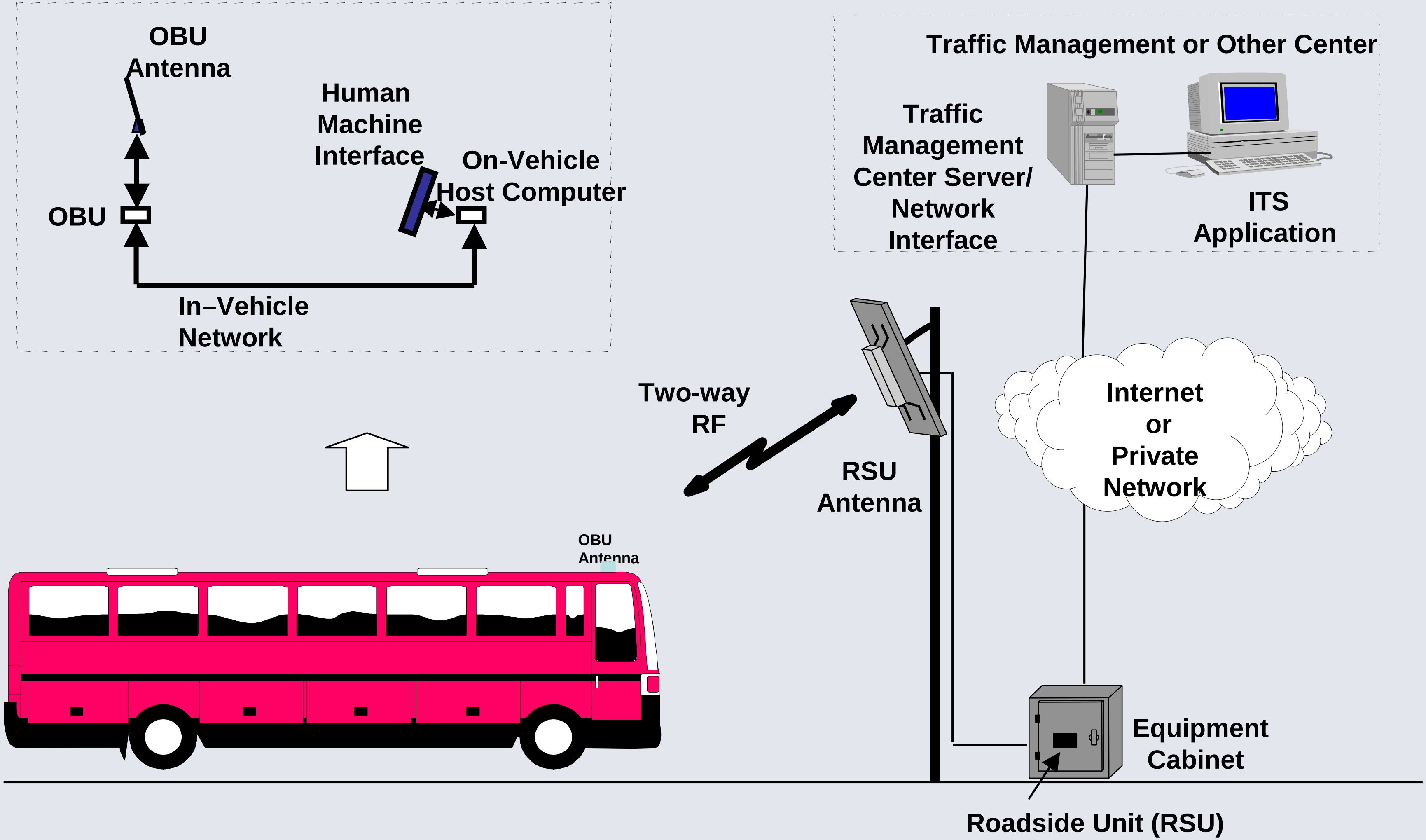
DSRC Radi0 Specifications

- Frequency Range: 5.855 – 5.925 MHz
- Data Rate: 6 Mbps - 27 Mbps
- Channel Bandwidth: 10 MHz
- Power output: 18 dBm
- Channel Switch Time: <= 2 us
- Internet Protocol Support: IPv6
- Operating Temperature: -10 to +70 deg C

DSRC Performance



DSRC and TSP


OBU
Antenna
Human
Machine
Interface
On-Vehicle
Host Computer
OBU
In–Vehicle
Network
Traffic Management or Other Center
Traffic
Management
Center Server/
Network
Interface
ITS
Application
Two-way
RF
RSU
Antenna
Internet
or
Private
Network
OBU
Antenna
Equipment
Cabinet
Roadside Unit (RSU)

Point-to-Point Systems

Spread spectrum techniques

Microwave systems

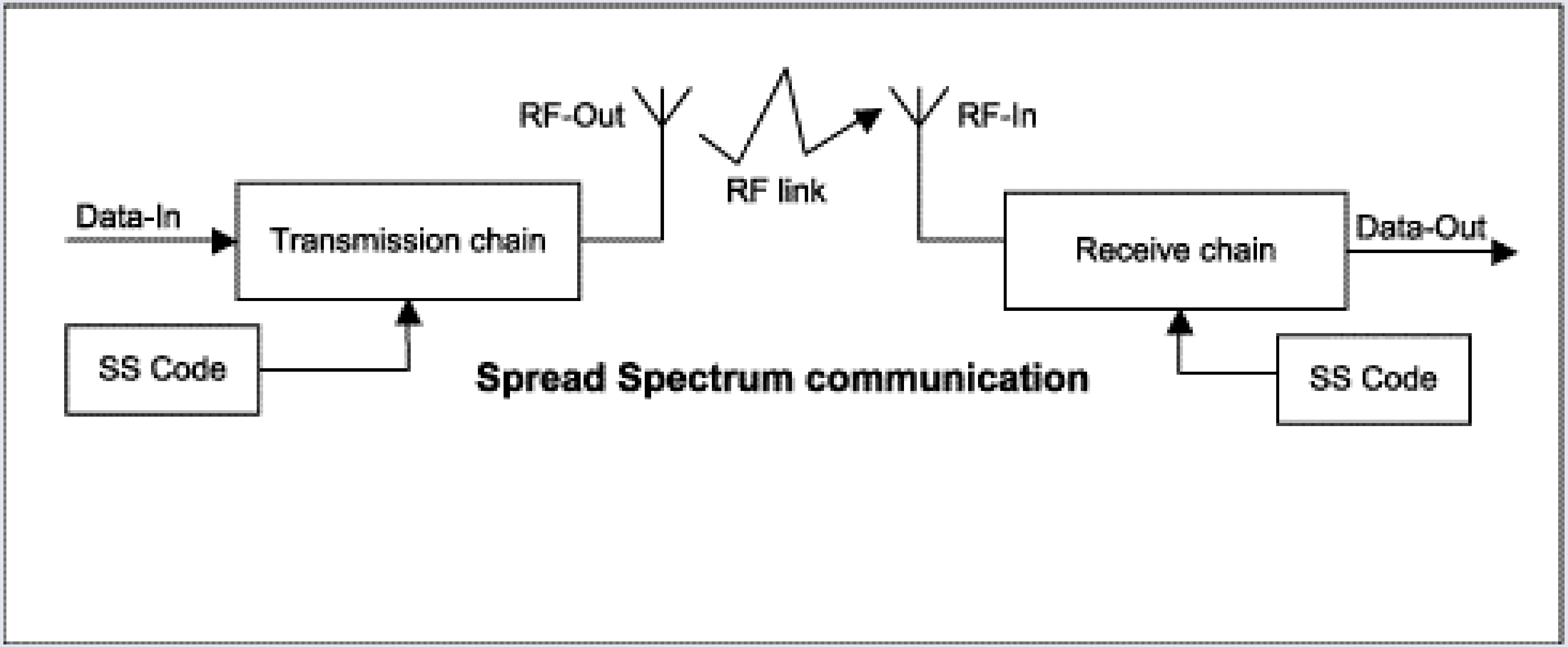
What is spread spectrum?

- A technology that “spreads” the transmission of data over a group of radio frequencies.
- Two techniques are used, frequency hopping and direct sequence
- Frequency hopping radio uses one frequency at a time and at pre-determined intervals jumps to another frequency
- Direct sequence spreads the transmission over several frequencies at the same time

Why Spread Spectrum?

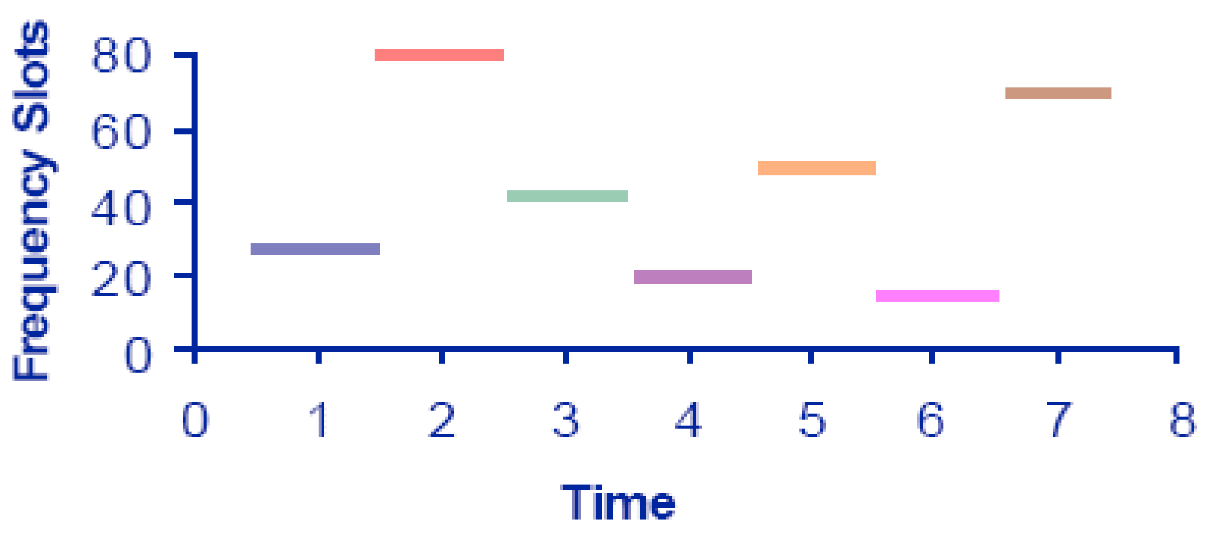
- Designed for unlicensed (ISM) radio bands (no need to deal with the FCC)
- Relatively immune to radio frequency interference
- Very secure
- Widespread use by wireless equipment manufacturers
- Cost effective

Spread Spectrum



Frequency Hopping

- Short duration “hops” between radio frequencies for data transmitted (each bit)
- Both sender and receiver know the sequence



Direct Sequence

- Original data is multiplied by a high bit rate "noise" signal then transmitted
- The noise is a pseudorandom sequence of 1 and -1 values
- The result is the outgoing signal's energy is spread into a much wider band compared with the original data signal
- The resulting signal resembles white noise (like an audio recording of "static")
- The noise is filtered out at the receiving end to recover the original data

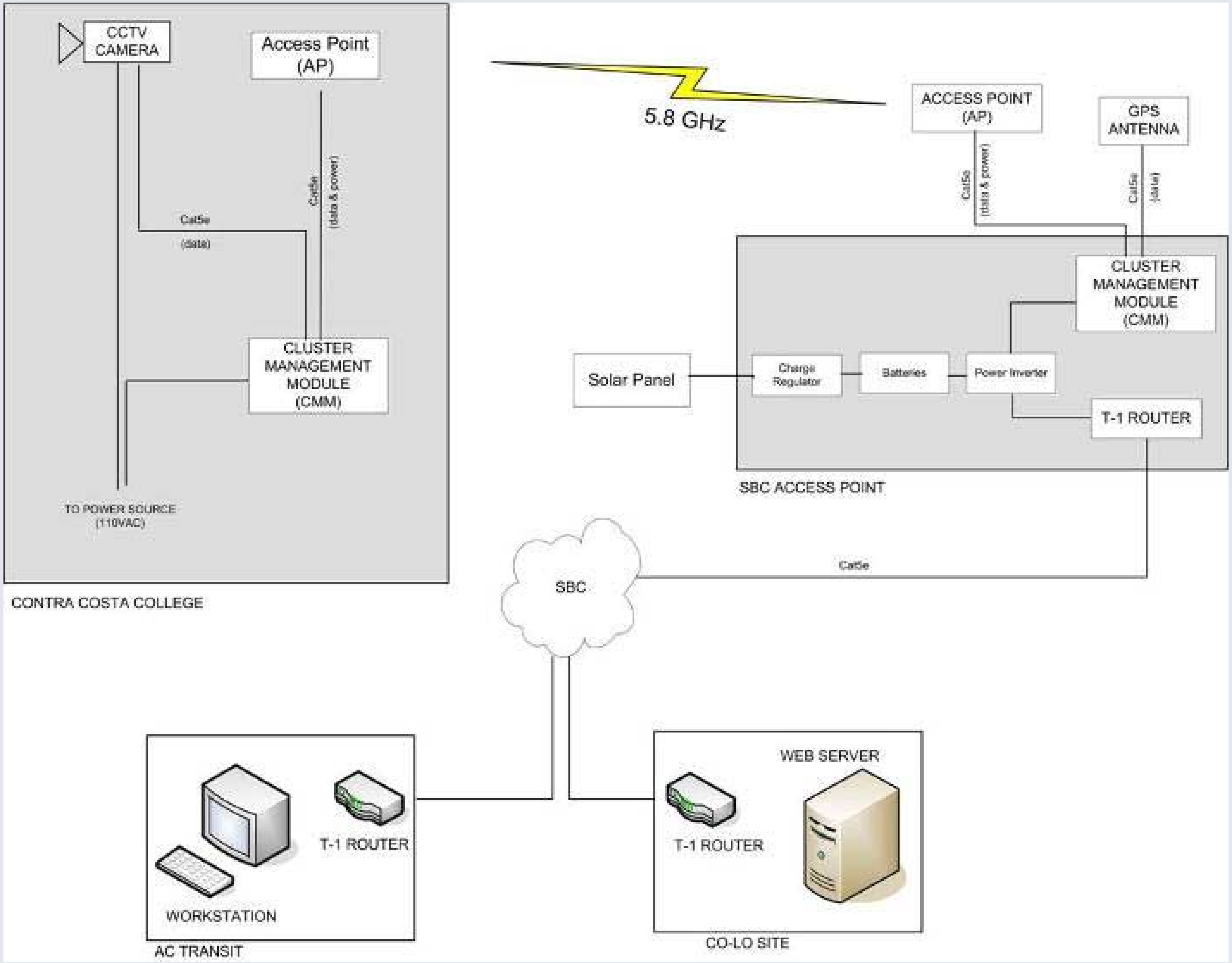
Frequency Hopping vs. Direct Sequence

- Direct Sequence:
  - Fixed wide channels
  - Prone to interference
  - Higher bandwidth
  - Typically deployed in the 2.4 GHz spectrum
- Frequency Hopping:
  - Narrow channel widths
  - Very immune to interference
  - Lower bandwidth
  - Typically deployed in the 900 MHz spectrum
  - Capable of multiple collocated antennas

Microwave Systems

- Requires direct line-of-sight
- Significantly impacted by weather (e.g, rain, fog) and obstructions (e.g, trees)
- Typically in the 5.8 and 24 GHz unlicensed spectrum
- Higher frequencies = higher bandwidth
- Can transmit over long distances with tall antenna heights
  - For example, a 100m high tower can transmit up to 80Km (line-of-sight)
  - Bandwidths as high 240 MBps

Microwave Systems



Cellular Systems

- First Generation: Analog
  - AMPS (USA)
- Second Generation: Digital
  - GSM/GPRS (1st Europe, then world-wide)
  - Digital AMPS (IS-54)
- 2.5: PCS
  - DCS-1900 (USA)
  - CDMA (IS-95, USA)
- Third Generation (3G): Personal Communication Systems
  - CDMA2000
  - UMTS

Cellular Systems

Cellular Technology	Frequency	Carrier
AMPS	800 MHz	AT&T, Verizon
CDMA	800, 1900 MHz	Verizon
	1900 MHz	Sprint
GSM	850, 1900 MHz	Cingular (AT&T), T-Mobile
iDEN	800 MHz	Nextel
TDMA	800, 1900 MHz	Cingular (AT&T)

AMPS

- Advanced Mobile Phone System
- Uses 800 MHz spectrum
- Service providers phasing out their AMPS infrastructure (e.g., Cellular Digital Packet Data - CDPD)
- Few providers support this infrastructure
- Not recommended for signal systems

GSM

- Global System for Mobile Communications
- Utilizes time division multiple access (TDMA)
- Circuit-switched, i.e., a dedicated circuit is established for each call
- Has an effective data throughput of about 9.6 KBps, e.g., text messages
- Cost depends on usage, but could be as high as $100/month

GPRS

- General Packet Radio System
- Uses same infrastructure as GSM
- Packet-switched
- Has an effective data throughput of up to 115 KBps (IP-based messages)
- Quick deployment with minimal installation requirements
- Cost = $40/month for service
- Works well for traffic signals if the system can tolerate long latencies

CDMA2000

- Code Division Multiple Access
- Multiple users on a channel each assigned a unique "code"
- Data rates between 153 to 307 KBps
- Cost depends on usage, but could be as high as $100/month

Wireless Systems Considerations

Lease vs. Own

Proprietary vs. Open Standards

Security and Reliability

Maintenance

Technological Obsolescence

Design Considerations

Lease vs. Own

- Equipment and services
- Capital costs
- Recurring costs vs. maintenance costs
- Network reliability (“up time”)
- Bandwidth

Proprietary vs. Open Standards

- Interoperability of different manufacturer’s equipment
- Integration with existing communication systems

Security and Reliability

- Utilize encryption for Wi-Fi systems
- More encryption = Less performance
- For example, frequency hopping is less susceptible to interference than direct sequence, but has a lower bandwidth
- Ensure that area is relatively void of frequency interference (conduct a site and path analysis)
- Leased services provide very secure links

Maintenance

- Staff training on technology and equipment
- How often to perform preventive maintenance
- Investment in required tools and equipment to perform maintenance functions, e.g., spectrum analyzer, GPS, bucket truck

Technological Obsolescence

- Use off-the-shelf equipment, e.g., yagi antennas
- Use standard interfaces, e.g. EIA-232, Ethernet
- If possible, select a wireless technology to accommodate increases in bandwidth, i.e., overprovision links
- For point-to-multipoint systems, design link capacity for expansion
  - For example, if a channel can handle up to six controllers based on bandwidth calculations, start with four controllers on that channel

Design Considerations

Line of sight

Antennas and radios

Radio spectrum

Interfaces

Testing

Design Considerations

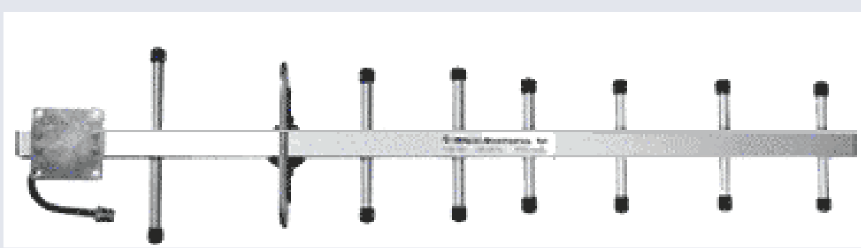
- Line of Sight

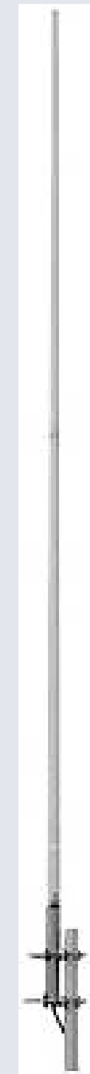
Line of Sight

- Need “RF” line of sight which includes fresnel zone
- Use a combination of strobe lights, mirrors (which reflect the sun), binoculars and spotting scopes.
- Visual verification, however, does not guarantee a clean line-of-sight – site and path analysis
- Anticipate tree and shrub growth in Spring and Summer months
- Place antenna as high as possible

Design Considerations

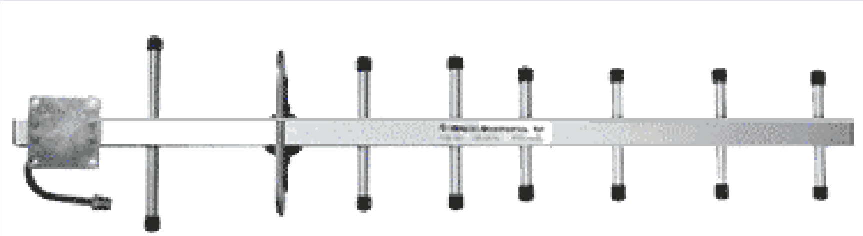
- Antennas and Radios
  - Directional vs. Omnidirectional



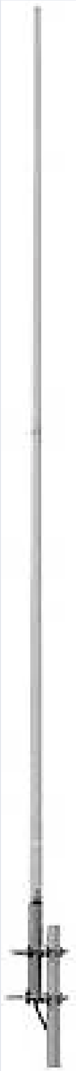


Directional antennas

- Signal energy is concentrated in the direction of the antenna
- Better for longer distance transmissions, i.e, higher gain
- More susceptible to obstacles



Omnidirectional antennas



- Better for multiple devices communicating with a single source
- Signal energy is spread evenly over the 360 degree radiation pattern
- Limited transmission distances due to low gain potential
- Less susceptible to obstacles

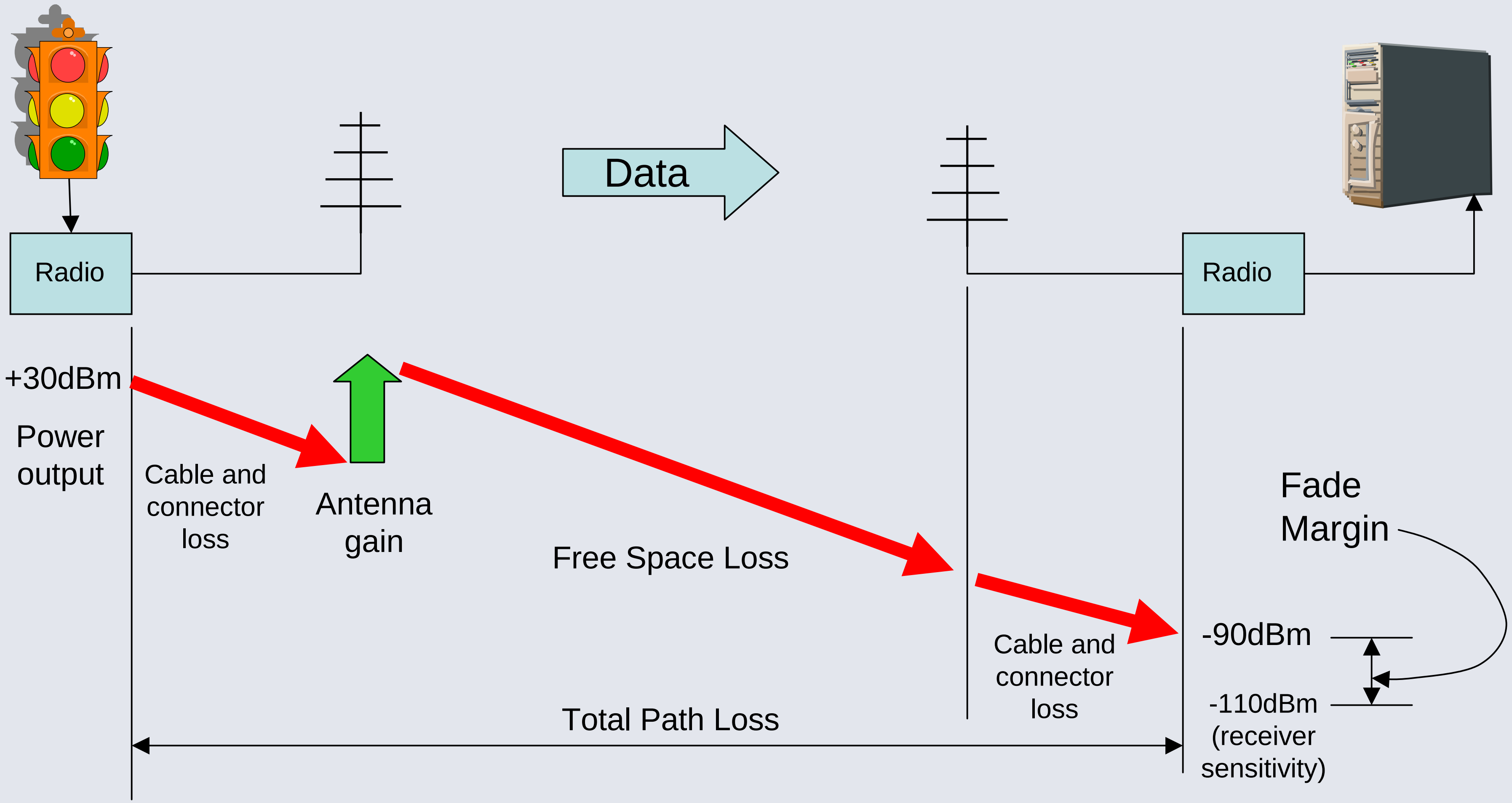
Radios

- For unlicensed ISM frequencies:
  - Radios limited to a maximum of one watt of power output
  - Radio plus antenna power output (effective isotropic radiated power, EIRP) limited to four watts maximum
- Alternatives:
  - Use maximum power radios and lower gain antenna
  - Use lower power radios and higher gain antennas

Design Considerations

- Radio Spectrum (unlicensed)
  - 900 MHz
    - Longer distance capability
    - Easier to “bend” around obstructions
    - Most reliable of the three
  - 2.4 GHz
    - Most crowded spectrum due to Wi-Fi
    - Transmits easily through walls
    - Heavily impacted by leaves and moisture
  - 5.8 GHz
    - Higher propagation loss, shorter reach
    - Higher bandwidth
  - 24 GHz
    - Highest propagation loss
    - Highest bandwidth
    - Rarely used for traffic signal systems
    - Sometimes used for point-to-point backhaul (trunking)

Free Space Loss



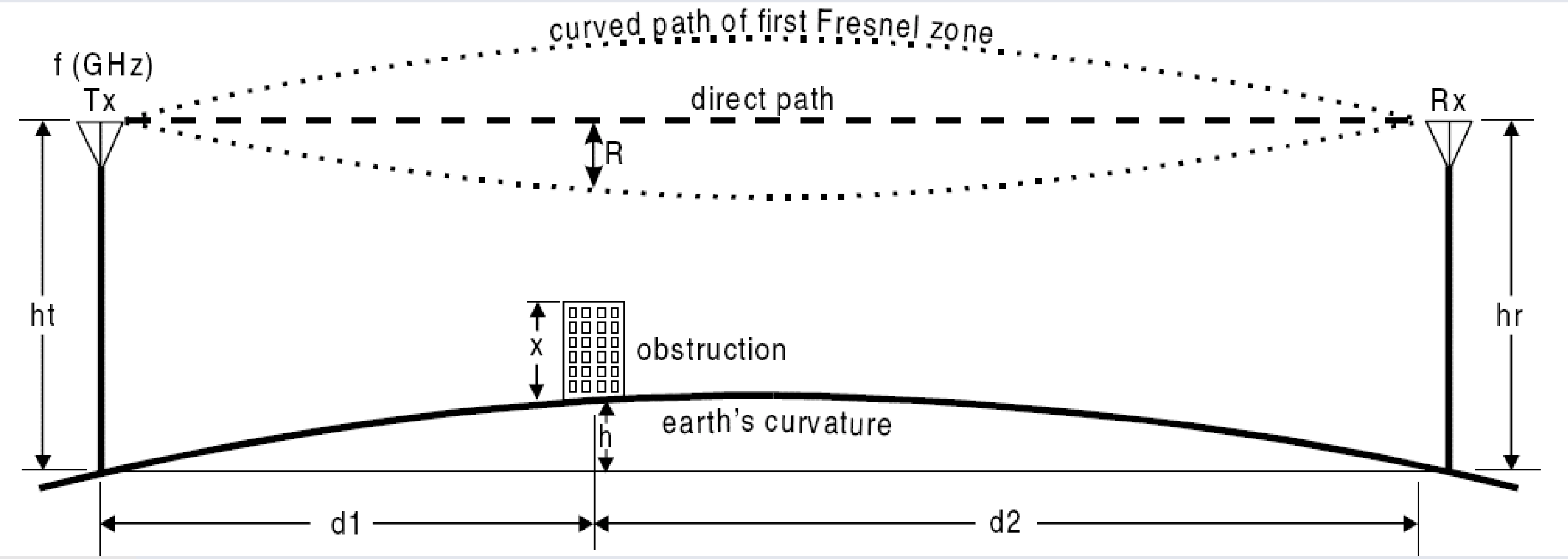
Free Space Loss = 36.56 + $20\log_{10}$(Freq. in MHz) + $20\log_{10}$(Dist. in miles)

A 2.4 GHz signal traveling 10 miles has a FSL of 124dB

Note: A measured value of -3dBm indicates a 50% loss in power, or signal strength.

Fresnel Zone

- Football shaped area between antennas
- Longer distances between antennas have larger fresnel zones
- Mounting antennas higher mitigates effects of fresnel zone
- Higher frequencies, smaller fresnel zones



Free Space Loss and Fresnel Zone

	900 MHz		2.4 GHz	
Distance between antennas	Fresnel Zone Diameter	Free Space loss (dB)	Fresnel zone diameter	Free Space loss (dB)
1000 ft (300 m)	16 ft (7 m)	81	11 ft (5.4 m)	90
1 Mile (1.6 km)	32 ft (12 m)	96	21 ft (8.4 m)	104
5 miles (8 km)	68 ft (23 m)	110	43 ft (15.2 m)	118
10 miles (16 km)	95 ft (31 m)	116	59 ft (20 m)	124
20 miles (32 km)	138 ft (42 m)	122	87 ft (27 m)	130
40 miles (64 km)	192 ft (59 m)	128	118 ft (36 m)	136

Typical Transmission Ranges

- 2.4GHz, 1W radio power plus 6dB gain antenna = 5 - 15 miles
- 900MHz, 1W radio power plus 6dB gain antennas = 15 - 25 miles
- 2.4GHz, 100mW radio power plus 16dB antennas = 10 - 40 miles
- 900MHz, 100mW radio power plus 16dB antennas = 20 - 60 miles

Interfaces

- Serial links need converters for Wi-Fi or IP/Ethernet-based networks
- Up-down converters for hybrid wireless systems, , e.g., between 2.4GHz and 900MHz

Testing

- Proper configuration and alignment
- Bandwidth analysis (throughput)
- Path loss
- Bit error rates
- Latency

BREAK